SETAC-Europe: Second Working Group on LCIA (WIA-2)

Best Available Practice Regarding Impact Categories and Category Indicators in Life Cycle Impact Assessment

Background Document for the Second Working Group on Life Cycle Impact Assessment of SETAC-Europe (WIA-2)[1]

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Preface

The present report constitutes a basis for the identification of best available practice concerning impact categories and characterisation factors for Life Cycle Impact Assessment. It is the result of the first working phase of the second working group on Life Cycle Impact Assessment of SETAC-Europe. In this working group also members from other divisions of SETAC participated, in particular from the US and from Japan. The following members of the working group have contributed to draft versions of the document. Most, though not necessarily all, of these comments were taken over by the editorial committee:

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[1] For the publication in Int. J. LCA, the report has been divided into two parts. Part I includes Preface, chapters 1-3 and the complete list of references. Part I appeared in No. 2 (March 1999). Part II comprises Preface, chapters 4 & 5 and repeats the complete liste of references.

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4 Proposals for Impact Categories

Below we present a proposal for a list of impact categories, with a main distinction between input related and output related categories. For every category the proposal includes: the area of protection involved, the content of the category (which environmental interventions, which processes and which endpoints are included) and the envisaged category indicator(s). In **Figure 4**, a preliminary overview is given of the causal relationships between environmental interventions, midpoints and (category) endpoints. This figure and the content of this chapter as such is not to be regarded as final, but rather as an open basis for discussion which will step by step absorb new scientific knowledge whilst replacing provisional links to endpoints by empirical or modelled relationships.

The scope of the work is to cover categories at all scale levels, including the local scale. Impacts at a local scale may well be treated by other analytical tools, but they cannot be treated in a comparable way. The reason for this is that at all levels of scale the functional unit-based LCA approach adds specific information compared with other tools. We may in our work programme, however, start with the global categories and go step by step down in scale. Also at the lower scale levels we will start with a global approach (integration of local effects over the whole globe). Where relevant remarks will be made on further work aiming at spatial differentiation for more detailed applications; but essentially this is to be the subject of a next round.

4.1 Input related categories

It is important to start with a discussion on the input related categories together in order to arrive at a consistent series. This is no doubt one of the most difficult subjects. A number of remarks can be made beforehand.

- A first point concerns the level in the environmental mechanism at which we will define the impact indicators, and consequently also the categories themselves. In principle, there is no objection against defining the categories at endpoint level, for instance "bio-diversity loss". However, that would not be an exclusive category, taking into account that also a number of output related categories (like eco-toxicity) will cause bio-diversity loss. As a starting point, we suggest not to bring input and output related impacts under the same categories. In case input and output related categories involve impacts on the same endpoints (like, in particular, bio-diversity), and if the indicators are chosen at earlier levels in the environmental mechanism, i.e. at midpoint level, we may for comparability reasons aim to develop additional indicators at endpoint level.
- A second issue concerns a main distinction between taking something out of the environment vs. different types of land use (i.e. changes within the environment or management of the environment).
- A third aspect concerns the possible distinction between deposits, funds and flows. In principle, these three types of use should all be covered; they refer to the speed of recovery in relation to the speed of extraction. Deposits are basically depleted as the renewal rate is extremely low, funds can be depleted and can recover, flows cannot be depleted and can only give rise to competition. In order to include also the flows in the scope, we rather should use the term "extraction" than "depletion of resources".
- A fourth point is that we must try to keep the categories as exclusive as possible. If the extraction of abiotic resources leads, apart from depletion of that resource, also to habitat destruction or to the emission of toxic substances, we should deal with the latter types of interventions in separate categories.
- And finally, we should keep in mind that the total number of categories will not increase too much; the set as a whole must be simple, considering the option of subcategories if necessary.

This leads us to the following proposal for the input related categories:

- category 1: Extraction of abiotic resources
- category 2: Extraction of biotic resources
- category 3: Land use, with the following subcategories:
  - subcategory: increase of land competition
  - subcategory: degradation of life support functions
  - subcategory: bio-diversity degradation

We will describe these categories, by identifying (a) area(s) of protection, (b) content of category and (c) possible indicator(s).

4.1.1 Extraction of abiotic resources

a) area of protection: natural resources
b) content of category: extraction of different types of non-living material from the natural environment; possibly three subcategories are to be distinguished, related to deposits, funds and flows:
   - sub-category 1: extraction of deposits (e.g., fossil fuels and mineral ores)
   - sub-category 2: extraction of funds (e.g., groundwater, sand and clay)
   - sub-category 3: extraction of flow resources (e.g., solar energy, wind and surface water)
c) possible (sub)category indicators (see for overview also FINNVEDEN, 1996 and HEIJUNGS et al., 1997):
   - rareness of resources
   - exergy content of resources (FINNVEDEN, 1998)
   - mineral concentrations (GOEDKOOP et al., 1998)
   - degree of use of flow resources in relationship to the size of the flow

- total material requirement (ADRIAANSE et al., 1997)
- indicators related to other categories, such as energy requirement or land use.

We propose that it must be studied first whether one category indicator can deal with these three subcategories together in a consistent way. If it appears to be impossible to define one overall indicator for all abiotic resources, separate indicators will have to be defined for the different subcategories. But it must be borne in mind that, even for one subcategory, different endpoints can be relevant, connected with different societal values, such as the present availability for society, the possibilities for future use of the resources, the usefulness of the resources for society related to their substitutability, or their energy potency. More clarity about these endpoints and connected values may help to agree on the best indicator(s) to be used.

4.1.2 Extraction of biotic resources

a) area of protection: natural resources and natural environment
b) content of category: extraction of specific types of biomass from the natural environment
c) possible indicator: it is questionable whether there will be a great need to aggregate biotic resources; but if there is a need to do so, an indicator may be developed aiming at describing the availability of the resources, based on the rareness (= measure of the stock) and on the regeneration rate of the resources. Some of the (sub)-category indicators of the abiotic resources could possible also be used here (FINNVEDEN, 1996). Note: this indicator should describe both the economic as well the inherent values connected with availability and depletion of the resource.

4.1.3 Land use

Here the types of impact and their underlying mechanisms are so different that we must distinguish between a number of aspects (cf. FINNVEDEN, 1996).

Subcategory 1: increase of land competition
a) area of protection: natural resources
b) content of category: physical interventions leading to exclusive land occupation, or to change in land occupation

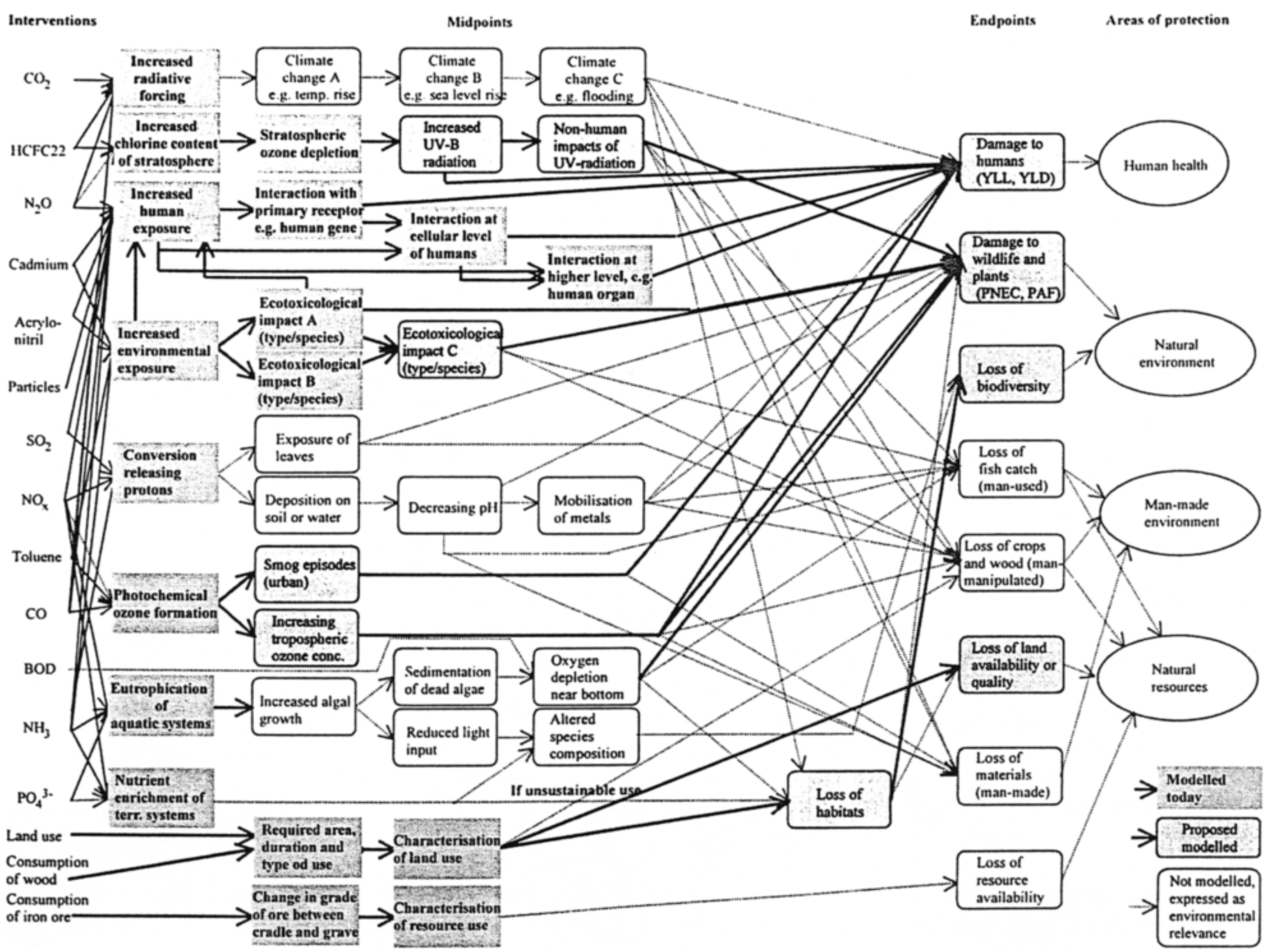

Fig. 4: Overview of the causal relationships between environmental interventions, midpoints and (category) endpoints

c) possible category indicators: area of exclusive land use for a given period of time; or: change in area of exclusive land use, possibly also including information on the resource quality of different types of land

Subcategory 2: degradation of life support functions
a) area of protection: natural environment, with links to human health and man-made environment
b) content of category: degradation of processes in the natural environment which are due to land use and have broad regulation functions; connected examples of such life support functions of the environment include: the cycling of nutrients in an ecosystem, the stability of the soil and the generation of soil fertility, the water household, and the generation of a suitable and stable microclimate
c) possible category indicators: vegetation cover, standing crop of natural vegetation, productivity of natural vegetation, soil permeability, and possibly others, again with a possible distinction between a lasting situation and a change

Subcategory 3: bio-diversity degradation due to land use
a) area of protection: natural environment
b) content of category: impacts of physical interventions on bio-diversity (ecosystems, species) as values in themselves (cutting of the vegetation, ploughing, paving, fragmentation of an ecosystem, lowering of groundwater table, fire, etc.)
c) possible category indicator: bio-diversity measure from a non-functional point of view, again with a possible distinction between a lasting situation and a change; a possibility concerns the loss of vascular plant species, in combination with the area involved (LINDEIJER, 1998); on the long term, it should be studied whether the impacts in this category can be characterised in a comparable way to the emission impacts on bio-diversity

There is a possible fourth subcategory of land use, dealing with the degradation of cultural values, like landscapes and monuments. This does well fit into this structure, but will not have a high priority for the LCA context.

4.2 Output related categories

The output related categories, i.e. the categories related to emissions, will be dealt with in the same way. We start with a general point and add some specific points per given category. In general, modelling up to the level of endpoints is regarded insufficiently certain. However, for some categories this still can be envisaged, particularly for human toxicity and eco-toxicity, because of the possibilities of science based aggregation. If this is done, the choice arises whether to limit these categories indeed to toxic impacts only, or to broaden the scope for possible other types of impact on these endpoints which are currently covered by other categories. We propose here to keep the scope of other categories as currently defined, i.e. including possible impacts on human health or on bio-diversity, although these types of impact are not modelled up to the endpoint level. In this way overlap is avoided. Where possible, we will advocate the possibility for defining an additional indicator at endpoint level, thus to increase comparability between categories without fusing them.

4.2.1 Climate change

This category is generally known under the heading "global warming"; it can better be called "climate change" because also storms or regional cooling can be part of the impacts. The modelling at the level of radiative forcing is rather well underpinned, less so impacts further along the impact network (displacement of Gulf Stream; release of methane from tundra's?). Therefore, there is as yet no basis for choosing the category indicator further along the impact network. It should be mentioned, however, that in the ExternE programme modelling at the level of endpoints is taken (EYRE et al., 1997). The choice of the most appropriate time period has to be considered; depending on the choice to be made regarding the temporal aspects (see question in section 3.3).

Proposal:
a) areas of protection: human health, natural environment, man-made environment
b) content of impact category: all impacts related to climate change caused by changes in radiative forcing
c) category indicator: radiative forcing

4.2.2 Stratospheric ozone depletion

Depletion of the stratospheric ozone layer leads to an increase of UV-B intensity at the surface of the earth, causing a number of radiation impacts: on algae and arctic flora, on crops, on wildlife and on humans. The first three are as yet rather uncertain; the latter can already be modelled with considerable certainty (cf. MÜLLER-WENK, 1997). As to the time period, a choice has to be made, depending on the choice to be made in section 3.3. In as far as relevant, possibly new modelling of background concentrations is necessary due to envisaged emission reduction.

Proposal:
a) areas of protection: human health, natural environment, man-made environment, natural resources
b) content of category: all impacts due to stratospheric ozone depletion (including possible impacts on human health)
c) category indicator: stratospheric ozone depleting potency of substances; in addition it will be analysed whether impacts on human health can be modelled in a comparable way to the human toxicity indicators

4.2.3 Human toxicity

This is one of the categories which does not yet meet the ISO requirement regarding the natural science basis. Here a promising path seems available in further modelling along the impact network, with indicators according to the concepts of YLL (years of life lost) and YLD (years of life with disability) as developed by (MURRAY and LOPEZ, 1996), and further in development for LCIA by HOFSTETTER (1998) and GOEDKOOP et al. (1998). Data availability needs to be analysed in order to test the feasibility of this approach as well as the possible level of detail. As these indicators only involve assumptions and no value choices, these will be acceptable according to ISO requirements. The number of disabilities or disability types can be very large, however. Therefore, the introduction of a disability weighting such as proposed in the DALY approach (disability adjusted life years) would be quite practical, as it avoids a too large number of indicators by aggregating the different types of disability life shortening. However, this latter aggregation clearly contains value choices. We therefore propose to define subcategories for the different types of disability. The weighting between these subcategories implies a first weighting step as described in section 2.6.

An important point regards the scope of the category. As suggested above impacts on human health caused by emissions which are dealt with in current other categories like climate change, stratospheric ozone depletion and photo-oxidant formation are to be included there. However, some extensions of the human toxicity category seem advisable, in particular regarding fine dust and radiation.

Special attention is needed for the work environment, which may also involve toxic chemicals. In a number of studies the work environment is defined as an impact category of its own. Because of the relevance of this subject, and because of the limited attention which has been given to it up to now, a new SETAC-Europe working group has been established for assessing impacts from the work environment. We propose that human toxicity aspects of the work environment are to be covered by the human toxicity category, by including these in fate modelling. Other aspects can then be dealt with in a separate category, hopefully enabled by the results from the SETAC-Europe working group.

Proposal:

a) area of protection: human health
b) content of impact category: all impacts on human health caused by the direct emission of toxic substances both outdoor and indoor, and impacts caused by fine particles and by radiation; definition of subcategories according to type of disability
c) category indicators: there are two types of indicators to be addressed: (1) indicators based on EC10 or NOEC values (cf. JOLLIET, 1996); (2) indicators such as YLL, with subcategory indicators like YLD and possibly a weighted indicator in terms of DALY (preferably to be readjusted so as to exclude age weighting)

4.2.4 Eco-toxicity

This is the second major example of incompatibility with ISO. The situation seems to be even more difficult to solve, because of the nearly unlimited number of species concerned. So a solution in terms of a broad indicator at the endpoint level such as YLL is not possible. At the same time, this also implies a very large number of mechanisms; splitting up to the level of common mechanisms is therefore beyond practicality. There seems to be only one solution: to model the impacts on a constructed indicator, which is a reflection of the species composition of one or more hypothetical ecosystems (terrestrial and aquatic) as a whole. This implies: no aggregation on basis of single NOECs, but an approach which aims at a higher level, although still based on single species tests in the laboratory.

For this aim a number of extrapolations are necessary: from laboratory to field; from acute to chronic; from EC50 levels to EC5, EC10 or to NOEC levels (if regarded relevant); from time dependent to time integrated including fate modelling; and most importantly, from single species to the species composition as a whole.

Here we focus for the moment on the latter aspect, for which there are at least two procedures:

1. The first concerns the PNEC approach, the predicted effects on the species composition as a whole; more precisely, the PNEC concerns the environmental concentration at which 95% of the species composition is regarded protected on a no-effect basis (or, respectively, 5% is regarded as not protected) (ALDENBERG and SLOB, 1991). This PNEC can be assessed on the basis of information about the species sensitivity distribution (Van STRAALEN and DENNEMAN, 1989), to be supplemented, in case of insufficient information on species sensitivity, with a procedure based on extrapolation factors. In principle, such extrapolation factors should only be applied as far as they are best and not conservative estimates like those from OECD, US-EPA (DOURSON and STARA, 1983) or EC (1993, 1996).

2. The second approach is the PAF approach (PAF = potentially affected fraction of species), directly aiming at the species composition itself (GOEDKOOP et al., 1998). Here the indicator is really at endpoint level; an important characteristic is that the chances regarding the non-affected fraction of species related to the different substances are multiplied with each other; this implies that the impacts of the substances are not regarded as independent from each other. Another difference is that the PAF approach takes non-linearity of the damage curve into account, in contrast to the PNEC approach (KLEPPER and VAN DE MEENT, 1997). With respect to the PNEC approach, we realise that it has not been developed for the aggregation of substances, but rather for the assessment of separate risk situations. In contrast, the PAF

approach performs the aggregation in a more science based way, and is also in development for this purpose; but it is more complicated in use and as yet not available. Both procedures should, if possible, be further explored, together with the other above mentioned extrapolations involved.

In addition, we may explore the possibility to work with robust, empirically established combined values of persistency and transfer factors regarding fate and exposure. And a further point to be discussed is the necessity of differentiating between terrestrial and (sweet and marine) aquatic ecosystems as possible subcategories.

Proposal:

a) areas of protection: natural environment, natural resources
b) content of category: all impacts on natural species and ecosystems caused by direct emission of toxic substances, including degradation products thereof; if necessary, subcategories can be defined for terrestrial and (sweet and marine) aquatic ecosystems
c) category indicators: if possible, indicators based on PNEC, i.e. concentration at which 95% of species of a hypothetical ecosystem is regarded protected (or 5% unprotected), based both on sensitivity distribution of species as well as on USEPA extrapolation factors, as recently done by Huijbregts (1999); or the PAF, i.e. the potentially affected fraction of species assessed by multiplication of chances regarding non-affected fractions of species for the different substances (as in development by Goedkoop et al., 1998); and further the traditionally used factors based on NOEC values or possibly ordinal factors (cf. Jolliet, 1996)

4.2.5 Photo-oxidant formation

As indicated above, this category will be dealt with as a unity, including impacts on human health. For the total of impacts the oxidant creation potentials are proposed as category indicator. Today, there are two approaches available:

1. Firstly, there are the photochemical ozone creation potentials (POCPs) which are developed for the European situation, taking into account average concentration levels of the relevant substances concerned (Derwent et al., 1998).

2. Secondly, there are the Maximum Incremental Reactivity (MIRs), developed in the US, which are of a more generic character as they are adapted to conditions of maximum oxidant creation (Carter, 1994). At a later stage, a choice has to be made here. An important point is that these oxidant creation potentials must be extended to include NO_x as catalyst in the process (Nichols et al., 1996) this is now being accomplished in the running Danish LCA programme.

Proposal:

a) areas of protection: human health, man-made environment, natural environment and natural resources
b) content of category: all impacts related to tropospheric oxidant formation, including impacts from NO_x emissions. There may be a need for distinguishing between two subcategories:
   - the short term and local impacts contributing to photo smog in the close vicinity of the source, primarily affecting human health and mainly caused by the more reactive VOCs
   - the medium term and more regional impacts primarily affecting crops and possibly natural vegetation, to a higher degree due to the more long-lived VOCs (alkanes)
c) category indicators: either the POCPs, i.e. the photochemical ozone creation potentials adapted to specific European conditions or the more generic MIRs; in both also NO_x is to be included, which may be more easily achievable under the above distinction of subcategories. Furthermore, there is also a high need for a sumparameter regarding VOCs because their composition is generally not given. In addition, it is likely that impacts on human health can be characterised further in a comparable way to the human toxicity indicators

4.2.6 Acidification

Acidifying substances cause a large diversity of impacts on soil, plants, animals and materials. Modelling up to the level of endpoints show quite varying data with changes in species composition, decreasing tree vitality and (still) increasing wood production (Kauppi et al., 1992); in addition this will still by necessity give a rather partial picture. So we propose to stick for the short term to H^+ release as category indicator. This is also compatible with ISO. But this asks for solving a number of boundary questions. These mainly concern the direct impact on leaves and needles, caused by SO_2 and NO_x; and cation exchange through leaf stomata and cation exchange in the soil absorption complex, both due to NH_x. We propose that these are regarded as being correlated with H^+, and therefore also to be considered as being part of the environmental relevance of the acidification indicator. Likewise, toxic impacts due to mobilisation of metal-ions such as Al are proposed to be regarded as belonging to acidification.

Furthermore, spatial differences in sensitivity and in fate and exposure are at stake, such as related to nitrification of ammonium, to denitrification and to buffering in the soil (Nichols et al., 1996). A simple fate procedure can start with the distinction between sensitive and non-sensitive areas such as the very sensitive Scandinavian ecosystems vs. the hardly sensitive calcareous grounds in the Southern part of Europe. More sophisticated procedures can be useful, for instance based on the RAINS model of IIASA, relating the H^+ load with regional sensitivity information in terms of

critical loads to ecosystems (cf. POTTING et al., 1998a,b). In the longer run, it is important to investigate whether a change of the indicator is possible to the endpoint level, e.g. in term of the percentage of affected species.

Proposal:
a) areas of protection: natural environment, man-made environment, human health, natural resources
b) content of impact category: all impacts due to acidification, including direct impacts on leaves, cation exchange in leaves and soil through ammonium, and mobilisation of aluminium and other toxic metals
c) category indicator: for the short term, (potential) release of H^+, if possible, differentiating between spatial differences in fate and sensitivity; for the long term, possibly a change to the level of the endpoints, including impacts on species and on human artefacts (crops, materials)

4.2.7 Nutrification

Nutrification includes all impacts due to an increased level of macro-nutrients, both in terrestrial as well as in aquatic ecosystems (cf. NICHOLS et al., 1996). Note: for aquatic ecosystems the term "eutrophication" is generally used; the term "nutrification" covers both. The impacts are less varied than those caused by acidification, as the natural vegetation is the only direct endpoint. The current indicator concerns the concentration of macro-nutrients, added up stoichiometrically. On basis of aquatic ecosystem functioning, we can calculate an equivalence with oxygen demanding material. An important question is whether we must add µp P and N without asking which nutrient is limiting. We propose that to be the preferable default. Then we can aim at further details by distinguishing between P- and N-limited conditions at a sub-continental level (including the distinction between large land and sea areas). Still one step further we can aim at a distinction between terrestrial and sweet-aquatic systems, amongst others distinguishing between the fraction of the emitted nitrogen which does and which does not reach the aquatic systems. This approach has, for example, been applied in the case study of the Finnish forest industry (SEPPÄLÄ, 1997).

As proposed above, cation exchange due to ammonium is regarded to be part of acidification; human toxic impacts due to nitrate in groundwater will be regarded to be included in human toxicity, comparable to the toxic impacts of SO_2. Stimulation of tree growth caused by N-deposition (often regarded as part of acidification) clearly belongs to nutrification. For the longer term, it is also relevant here to study a possible change of the category indicator to the endpoint level, e.g. in term of the percentage of affected species.

Proposal:
a) areas of protection: natural environment, natural resources (impacts on fish catch) and man-made environment (wood and crop productivity)
b) content of impact category: all impacts of macro-nutrients on the vegetation, both natural as well as crops, both terrestrial as well as aquatic, and indirect impacts thereof; a sub-categorisation between terrestrial and aquatic ecosystems may be envisaged, due to the differences between the environmental mechanism of both types of systems
c) category indicator: for the short term, stoichiometric sum of macro-nutrients, if relevant differentiating between terrestrial and aquatic systems; on the longer term, a change to the endpoint level can be envisaged. In aquatic ecosystems also the impact of BOD can be considered, requiring the definition of the indicator at the level of oxygen depletion.

5 Concluding Remarks

Above a list of impact categories is given, together with a indication of best available practice regarding category indicators. This list is not complete and neither final. For instance, additional impacts caused by noise and odour, impacts caused by physical accidents, or non-toxic impacts related to the work environment have also to be considered. It is proposed that these are taken along as far as possible in comparable way to the human toxicity category and that it will be subsequently decided how to deal with these types of impact. In part, this can be supported by information from the SETAC-Europe working group on work environment.

The present report has to play a role in the guidance of the scientific task groups. It is to be expected that input from these task groups will lead to changes in the present content of the report. If such changes go beyond the reach of separate categories and also have a more general bearing, they must be discussed in the working group as a whole in order to achieve consistency in the field of Life Cycle Impact Assessment as a whole.

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